LOADING PROBLEM IN FMS : PART MOVEMENT MINIMIZATION

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S. RAJAMARTHANDAN

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Certified that the present work on **Loading Problem in FMS Part Movement Minimization** by S.Rajamarthandan has bee carried out under my supervision and has not been submitt elsewhere for the award of degree.

April 28, 1988

Dr. Kripa Shanker
Professor
Industrial & Management Engg.
Indian Institute of Technology
Kanpur 208 016

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CONTENTS

ABSTRACT

Loading problem in dedicated Flexible Manufacturing System (FMS) with the objective of part movement minimization is formulated as 0-1 linear integer programming problem by exploiting certain special characteristics of the problem. Standard branch and bound tecnique is proposed to use for solving the problem. The model is modified further to accomodate the bi-criterian objective of load balancing and part movement minimization. A simulation approach is suggested for the composit scheduling problem of loading and sequencing in random FMS. The model formulated for the dedicated FMS after appropriate modifications to suit the random environment, is used to experiment the effect of loading policies in conjunction with the dispatching rules (FIFO, SPT, LPT). A supporting system is developed for the combined problem of loading and sequencing in dedicated FMS to provide assistance in making decisions regarding the selection of loading and dispatching rules in the light of their effect on important system performance measures. The coding for the simulation programme and the supporting system is done in Turbo Pascal.

CHAPTER I

FMS : A BRIEF RESUME

For years manufacturing industry has been faced with ever increasing complexities in a production system with medium volume production and several product designs. This increased complexity has been due in part to increases in part mix, volume of parts, part design complexity, machine capablities and varying machine production rates. In many cases these factors have contributed to an overall decrease in productivity. Resulting from these problem has been the development of Flexible Manufaturing Systems, popularly called as FMS, with the objective of eliminating or minimizing some of the inherent complexities while bringing together the high productivity features of mass production and the flexibility of jobshop into a batch type of production system. There have been a variety of attempts to define what is meant by Flexible Manufaturing System. To brief some of them,

1) An FMS is typically defined as a set of machine tools linked by a material handling system, all controled by a computer system (Kusiak [11]).

2) An FMS is a complex system consisting of many interconnected components of hardware and software, as well as many limited resources such as pallets, fixtures, tool magazines (Suri et al. [22]).

3) FMS combines the existing technology of NC manufacturing, automated material handling and software to create an integrated system for the automatic random processing of palletized parts accross various work stations in the system (Buzacott [5]).

A Flexible Manufaturing System in general consists of a group of processing stations - numerically controlled machines, machining centres with automatic tool interchange capabilities and robots - linked together with an automatic material (work part) handling system and an automatic storage and retrieval system that operate as an integrated system under the control of a central computer. The work parts are on pallets which move through out the system, transfered by transfer lines located beneath the floor or by some other mecahanism. the system limits handling by the operators and can be more readily programmed to handle new requirements.

Flexibility is the essential feature of FMS. In general, flexibility could be defined as the ability to respond effectively to changing circumstances. A flexible system is thus, one which is able to respond to cahange. It is said to have <u>state flexibility</u> if the capacity of responding to change is contained with in the system while it has <u>action flexibility</u> if effective intervention required for responding to change must come from outside the system. In the context of FMS, the emphasis on flexible implies state flexibility. Most of the emphasis on achieving flexibility in manufacturing systems has related to job flexibilty, that is, the ability of the system to cope with

changes in the jobs to be processed by the system. Essentially this can be achieved either at machine level or at system level. At the machine level job flexibility can be achieved by increasing the capabilities of the machines while at the system level by distributing the required capacity to a variety of machines or work stations, each of which would then be specialized to certain processing tasks. A major emphasis in FMS should be to achieve the flexibility at the system level for the given set of machine tools and other facilities.

A Flexible Manufacturing System may be considered to consist of the following sub systems viz (1) Management system, (2) Production system (machines and toolings), (3) Material handling (transfer) system and (4) Computer system. Fig.1 shows the relationship amongst the subsystems and presents the hierarchical structure (Kusiak [10]).

While an FMS posseses the attractive combination of automation and flexiblity, the production management problems are rather more complex as compared to mass production or jobshop production. O'Gradey and Menon [14] state that there is universal acceptance of the observation that planning and control in FMS is an immensly complex problem. This is mainly because (1) each machine is quite versatile and capable of performing many different operations, (2) the system can machine several part types simultaneously, and (3) each part may have alternate routes through the system. These additional capabilities and planning options increase both the number of variables and the constraints associated with setting up an FMS. To best utilize the FMS' capabilities, a careful system set up is required prior to actual

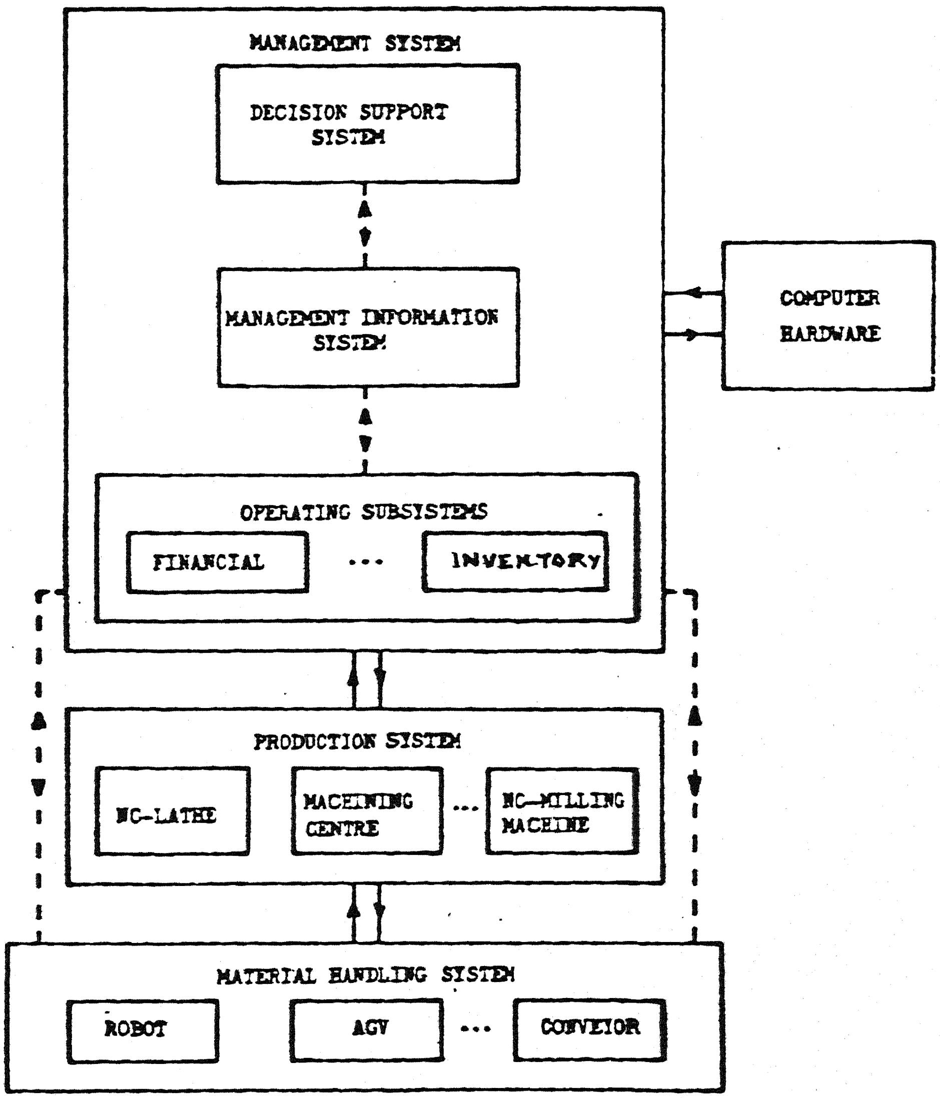


Fig. 1: Hierarchical structure of FMS.

production. The planning phase involves several production planning problems, they are breifed by Stecke [19] as

(1) Part Type Selection

From a set of part types that have production requirements, determine a subset for immediate and simultaneous processing.

(2) Machine Grouping

Partition the machines into machine groups in such a way that each machine in a particular group is able to perform the same set of operations.

(3) Determining Production Ratio

Determine the relative ratios at which the part types selected will be produced.

(4) Resource Allocation

Allocate the limited number of pallets and fixtures of each type among the selected part types.

(5) Loading

Allocate the operations and required tools of the selected part types among the machine groups subject to technological and capacity constraints of the FMS.

Flexible Manufacturing Systems can be classified in to two groups (1) Dedicated type (2) Random type. In dedicated type, the system is designed to produce a rather small family of similar parts with a known and limited variety of processing requirements. As an impact of competetive market environment and

consistant tecnological developments, the product designs are also undergoing considerable changes while the new designes are developed at a monumental rate. Consequently, there is a gradual shift from FMS dedicated type to FMS capable of responding to new changes, the later refered to as random FMS. In random FMS, a large family of parts having a wide range of characteristics are produced and the product mix is not completely defined at the time of installing the system.

The present thesis deals with the loading problem in both dedicated and random FMS.

CHAPTER II

LOADING AND SCHEDULING PROBLEM IN FMS

In FMS the loading problem is to assign the operations of the part types required to be produced and the tools necessary to perform the operations to the machines, subject to the FMS technological and capacity constraints and according to some loadig objectives, in a way that will best utilize the machines or maximize production, when the system is running. Once this problem is solved the cutting tools are loaded into their assigned tool magazine(s), then the system is ready to begin production.

Scheduling in automated manufacturing systems can be described by a hierarchical structure ranging from top level decision making to detailed level sheduling decisions. Top level sheduling emphasizes planning for production and plant operations over extended periods of time. At the detailed level, with which the present thesis is concerned, scheduling controls production over the course of each day and provides means to achieve production targets. It comprises the allocation of machines to the jobs and the sequencing of jobs on allocated machines.

2.1 Literature Review

The high capital investment for the machine tools and various other components of FMS will be justified only when there is optimum utilization of the resources. This is influenced by

the planning decisions prior to the actual production. Hence the loading problem in FMS as it is one of the planning decisions, becomes more important. There have been substantial number of research works in this particular problem of FMS. Though the basic definition of loading does not differ with the type of FMS, that is, whether dedicated or random, the approach to solve them varies significantly.

In dedicated FMS the product mix is completely known and the loading problem is less complex than in random FMS. As a result of flexibility and capabilities of FMS, loading can be done with more number of objectives as compared with conventional manufacturing systems where usually load balancing will be of main concern. Stecke [19] has described the following six objectives of loading.

(1) Balancing the machine processing times (in order to equally distribute the idle time over the machines and to reduce the production cycle time for high throughput rate and high machine utilization).

(2) Minimizing the number of movements (in order to reduce the material and tool handling cost for a high throuhput rate).

(3) Balancing the work load per machine for the system of groups of pooled machines of equal size.

(4) Unbalancing the work load per machine for the system of groups of pooled machines of unequal size.

(5) Filling the tool magazine as densely as possible (for the maximum utilization of slots).

(6) Maximizing the sum of operation priorities.

The following solution methedologies for loading in dedicated FMS have been suggested. Stecke [19] has formulated the loading problem as 0-1 non-linear integer programming problem and has examined several linearization techniques. The non-linear terms involved in the formulation makes the problem size large interms of the number constraints and variables, after linearization. This will make the problem intractable for real life situations, hence Stecke and Talbot [20] have suggested the need for fast heuristic procedure that gives good solutions. The combined problem of grouping and loading with more than one objective is formulated as multistage multiobjective optimization model by Kumar et al. [9]. A hierarchical approach comprising aggregate and detailed models is suggested by Stecke [21] to solve the machine grouping and loading problem. In the line of ref [19], a mixed non-linear programming formulation is proposed by Padhye et al. [15] with the consideration of important planning aspects of refixturing and limited tool availability. A loading problem in FMS where tool is allowed to move between the machines by keeping the parts fixed on a sigle machine has been cosidered by Na et al. [13]. The problem is modeled as a non-liner integer programming problem, and an effecient solution procedure is proposed.

In random FMS where the product-mix is not completely defined at the time of installing the system, the loading problem is specified as selecting a subset of jobs from the job pool, and assigning their operations to the appropriate machines with certain objectives. The objectives mentioned for dedicated FMS remain valid for random type also. A bi-criterion objective of balancing the workload among the machines and meeting the job due

dates is considered by Shanker and Tzen [16]. Heuristic methods have been suggested and their performances have been compared with the exact MIP solution. A branch and backtrack approach for the solution of loading problem with the objectives of maximizing the assigned workload and minimizing the job lateness is suggested by Srinivasalu [17], due to the computational complexity in solving the problem, simpler heuristics are also proposed.

For loading and sequencing problem in FMS, a procedure using MIP formulation is suggested by Green and Sadowski [7]. An experimental investigation of operating strategies for an existing FMS is reported by Stecke and Solberg [18], where they have examined 16 dispatching rules versus 5 loading strategies. The study draws several significant conclusions about how the system should be controlled, and indicates that the choice of applicable loading and scheduling strategies depends on many variables particular to the system. The study does not consider the due dates of the jobs. A simulation model is developed and effects of loading on system performance and different dispatch rules are examined for random FMS environment in ref. [16]. A fairly exhaustive review of scheduling rules in FMS is given by Gupta et al. [8]. Doulgeri et al. [6] present scheduling algorithm which embed an FMS simulation model which can take into account of fixtures and material handling system. A simulation model for design and evaluation of scheduling strategies has been developed by Madhusudhanan [12]. The loading stage of the problem is not considered seperately.

2.2 Scope of the Thesis

The present thesis deals with loading problem in random and dedicated type FMS, and a simulation model is developed and experimented for loading and sequencing problem in random FMS.

In Chapter III, the loading problem with an objective of part movement minimization is formulated as a linear integer programming model by realistic assumptions and suitable exploitation of certain characteristics of the problem. Branch and bound technique or enumeration technique suggested by Balas [1] is proposed to use for solving the problem. The model is extended to consider the bi-criterion objective of part movement minimization and workload balancing.

In Chapter IV, a simulation approach is suggested for the problem of loading and sequencing in random FMS. The formulation described in Chapter III is used after appropriate modifications. Two loading policies are examined in conjunction with three dispatching rules, using the approach suggested. The simulation programme is coded in Turbo Pascal.

A supporting system is designed and implemented for the purpose of loading and sequencing in dedicated type of FMS. This provides assistance in selecting satisfactory combination of loading and dispatching rules, and can be used to find the number of transportation vehicles which can be employed to make the best use of the system.

Conclusions and suggestions for future research have been presented in Chapter VI.

CHAPTER III

LOADING PROBLEM IN DEDICATED FMS

In this chapter we consider the loading problem in dedicated FMS. The dedicated type FMS is designed to produce a rather small familiy of similar parts with a known and limited variety of processing requirements. Such a system usually employes special types of machine tools. All the part types to be produced can be assumed to be available at the time of assignment.

3.1 Mathematical Programming Formulation

3.1.1 Conceptual Model for the FMS under Consideration

The elements of an FMS viz, machine tools, jigs and fixtures and material handling systems can be configured in several different ways depending on the manufacturing needs. It is therefore necessary to define the configuration of the FMS under consideration as precisely as possible.

We consider an FMS consisting of M machines, each machine is assumed to have general processing capabilities, to accomodate a range of different manufacturing operations. Thus such a machine can be deemed to be a machining centre. A machining centre is assumed to be equipped with a tool magazine of limited capacity. The cutting tools required for all operations that might be performed by a particular machining centre are stored in its tool magazine.

The parts to be processed are transported to and from the machining centres by an automatic material handling system. The

number of different operations that is possible on a machining centre is dependent upon its inherent capability, and the capacity of the tool magazine. Therefore a job with different operations may be completed on the machining centre, if all the required tools are available on its tool magazine. However, most often this is not possible due to technical and/or environmental constarints of the system such as special demand of a machining centre by several parts, the capacity of a machining cenetre, the limited number of tool copies and the limited capacity of tool magazine. Then there are two ways of completing the operations, one is the required tools are brought from other machining centre, another is the part is moved to the machining centre where the tools are available. The first practise is refered to as 'Tool Movement Policy', while the second as 'Part Movement Policy'. We shall be concerned with 'Part Movement Policy'.

3.1.2 Minimizing the Part Movements

The operations allocation with the objective of minimizing the number of movements of the parts between machining centres is relevant when the transportation time (or the distance between machinig centres) is large relative to the average operation time. Stecke [18] has observed that there are manufacturing systems for which minimizing part movements is preferable even at the expense of load balancing. Some relative advantages of minimizing part movements as compared to other objectives of loading are as follows.

1) When several consecutive operations require the same machine type, time may be saved by processing all of them on the same machine, if technologically possible.

2) Both travel time (from machining centre to machining centre) and waiting time (for busy next machining centre or transportation vehicle to become free) can be decreased significantly if a part stays on its current machine to process its next operation rather than moving.

3) Some times part movement may cause serious technical difficulties when high precision is required for part processing. A part must be repositioned so that an exact referance point is initialized every time it visits a different machining centre. This may be impractical for modest tolerances and impossible in some extreme cases.

Problem Statement

Given the part types to be produced with their operations and the machining centres with their capabilities and capacities, the problem is to allocate the operations on the machining centres so that the number of part movements between the machining centres is minimized. That is equivalent to minimizing the seperation of succesive operations of the parts. Such a problem usually has to be solved with the presence of several constraints.

Assumptions and Notations

Assumptions made for the purpose of modelling are as follows.

1) Part types have already been selected for production, hence they are completely known for loading decision.

2) The sequence of operations for each part is unique and known.

3) All the machining centres are identical and can perform operations on any part type if necessary tools are provided.

4) Tool slot requirement for the tools corresponding to an operation depends only on the type of operation and is independent of the part type and the machining centre.

5) Each magazine has a limited capacity for holding tools.

6) An opeartion cannot perform until all the required tool for the operations are placed in the magazine.

7) An operation is assigned to only one machining centre.

8) Duplication of a tool is not permitted in the same tool magazine.

9) All operations can be uniquely identified by the type of tools they require.

Notations

The following notation for indices, parameters, decision variables is used.

Subscripts

i	:	part index
j	:	operation index
k	:	machine index
u	:	operation type index

Parameters

P	:	Number of parts
M	:	Number of machining centres

O_i : Number of operations of part i

b_k : Tool magazine capacity of machining centre k

$t_{i,j}$: Tool slot requirement of operation j of part i

$p_{i,j,k}$: Processing time of operation j of part i on machining centre k

S : Set of all operations of all parts $\{(i,j) \mid i = 1,2 .. P ; j = 1,2 .. O_i\}$

NS : $|S|$

W : Set of all type of operations

T_u : Set of all operations of type u or equivalently operations which use tool type u

NT_u : $|T_u|$

C_u : No. of tool copies in tool type u

B : Index subset of T_u such that $|B| = p$; $p = 1,2..NT_u$

Decision Variables

$$X_{i,j,k} = \begin{cases} 1 \text{ if operation } j \text{ of part } i \text{ is assigned on machining centre } k \\ 0 \text{ otherwise} \end{cases}$$

Objective Function

The objective is to minimize the seperation of the succesive operations of the parts. If j and j+1 represent consecutive operations then

$$X_{i,j,k} - X_{i,j+1,k} = \begin{cases} 0 \text{ if operation } j \text{ and } j+1 \text{ are assigned on the same machining centre } k \\ \pm 1 \text{ otherwise} \end{cases}$$

Hence $\sum_{i=1}^{P} \sum_{j=1}^{O_i-1} \sum_{k=1}^{M} |X_{i,j,k} - X_{i,j+1,k}|$ represents the excess part movement.

The modulus function is replaced by square function for computational feasibility, thus the objective function becomes

$$\text{Minimize} \quad \sum_{i=1}^{P} \sum_{j=1}^{O_i-1} \sum_{k=1}^{M} (X_{i,j,k} - X_{i,j+1,k})^2 \qquad (1)$$

Constraints

1) Tool slot constraint

The tool slot capacity relates the number of slots required by the operations assigned to a machining ceentre to the total number of slots contained in the tool magazine. The constraint, in its simpler form can be expressed as

$$\sum_{i=1}^{P} \sum_{j=1}^{O_i} X_{i,j,k} \, t_{i,j} \le b_k \qquad k = 1,2..M$$

This constraint may be complicated in view of the fact that different operations of different parts can require the same tool when they are of the same type of operation. If two or more operations require the same tool and only one tool can be used at

a time, it is unnecessary to assign more than one copy of the same tool to the same machine when it can perform all the operations without considerable wear.

The tool magazine capacity constraints as formulated by Stecke [19] are proposed to use for this purpose, that is,

$$\sum_{(i,j)\in S} t_{i,j}\, X_{i,j,k} + \sum_{p=2}^{NS} (-1)^{p+1} \sum_{\substack{\text{for all possible } p \\ \text{combination of opera-} \\ \text{tions } (i,j)\in S}} t_{i,j} \prod_{\substack{\text{for a given } p \text{ combi-} \\ \text{nation of operations}}} X_{i,j,k} \le b_k \qquad (2)$$

2) Unique Job Routing

Each operation of each part type must be assigned to one machining centre, i.e.,

$$\sum_{k=1}^{M} X_{i,j,k} = 1 \qquad i = 1,2 \,..\, P \;;\; j = 1,2 \,..\, O_i \qquad (3)$$

3) Tool assignment constraint

The number of tool copies assigned to all the machining centres combined cannot exceed the available tool copies, that is,

$$\sum_{k=1}^{M} f(X_{i,j,k} \mid (i,j)\in T_u) \le C_u \qquad u = 1,2 \,..\, G \qquad (4)$$

where

$$f(X_{i,j,k} \mid (i,j)\in T_u) = \begin{cases} 1 & \text{when any one or more of the operation } (i,j)\in T_u \text{ is assigned to machining centre } k \\ 0 & \text{when none is assigned} \end{cases}$$

Hence $\sum_{k=1}^{M} f(X_{i,j,k} | (i,j) \in T_u)$ will be the number of times tool type u is assigned.

The function is defined as follows

$$f(X_{i,j,k} | (i,j) \in T_u) =$$

$$\sum_{(i,j) \in T_u} X_{i,j,k} + \sum_{p=2}^{NT_u} (-1)^{p+1} \sum_{\forall B \subseteq T_u \ni |B| = p} \prod_{(i,j) \in B} X_{i,j,k}$$

This constraint will be active when $C_u < \min \{|T_u|, M\}$

4) Integrality of decision variables as 0-1 integers

$$X_{i,j,k} = 0 \text{ or } 1 \quad i = 1 \,..P \;;\; j = 1..O_i \;;\; k = 1...M \qquad (5)$$

Modifying the formulation

Objective function

The non-linear terms in the objective function can be reduced by using the binary nature of the variables as follows.

$$\text{Min } (X_{i,j,k} - X_{i,j+1,k})^2 \equiv \text{Min } (X_{i,j,k} + X_{i,j+1,k} - 2X_{i,j,k}X_{i,j+1,k})$$
$$\equiv \text{Max } (X_{i,j,k} \times X_{i,j+1,k})$$

This modification gives the meaning of maximizing the assignment of succesive operations together.

In the above expression the quadratic terms can be linearized using linearization technique suggested by Balas[10] by

introducing one variable and two constraint for each quadratic term.The new variable $Y_{i,j,k}$ is introduced for each product term $X_{i,j,k} \times X_{i,j+1,k}$, and will be a binary variable. the objective function then can be expressed as

$$\text{Max} \sum_{i=1}^{P} \sum_{j=1}^{O_i} \sum_{k=1}^{M} Y_{i,j,k} \tag{1a}$$

The additional constrailnt sets as

$$X_{i,j,k} + X_{i,j+1,k} - Y_{i,j,k} \leq 1 \tag{1b}$$

$$-X_{i,j,k} - X_{i,j+1,k} + 2Y_{i,j,k} \leq 0 \tag{1c}$$

Tool slot constraint

The fact that operations which use the same tool types are the same in respect of their tool slot requirement in the tool magazine, can be exploited to reduce the non-linearity in the constraint.

A new variable set Zu can be defined for every element (type of operation) u of the set W, that is

$$Z_{u,k} = \begin{cases} 1 & \text{when operation u of set W is assigned to machine k} \\ 0 & \text{otherwise} \end{cases}$$

These new variables can be used to represent the resource (tool magazine) consumption by the operations.

The subscript u denotes the index of the type of operations in the set W. This index can be defined for an operation (i,j) by a conceptual function ϕ. For example, let us consider a part type 2 (i.e, i=2) which has 'Milling' as the third operation in its operation sequence (j=3) and the milling operation is the first element (or equivalently having index = 1) in the set W. Now the function ϕ can be defined as,

$$\phi(i,j) = \phi(2,3) = 1$$

The new variables $Z_{u,k}$ have to be related with the variable set $X_{i,j,k}$ in such a way that when operation (i,j) is assigned to a machining centre k, that is, $X_{i,j,k} = 1$, then the corresponding index of the element of the set W, $\phi(i,j)$ should be assigned in the same machining centre, that is, $Z_{\phi(i,j),k} = 1$. This results the following additional constraint set.

$$\sum_{k=1}^{M} X_{i,j,k} Z_{\phi(i,j),k} = 1 \quad i = 1,2..P;\ j = 1,2,..O_i$$

Let us notice the following property that for a machine k when $X_{i,j,k} = 1$ then $Z_{\phi(i,j),k}$ should be 1 and when $Z_{\phi(i,j),k} = 1$, $X_{i,j,k}$ need not be 1. Further explaining this, let us consider the previous example and assume one more part type 4 (i.e. i = 4), which has 'Milling' as its first operation in its operation sequence. And we assume the assignment where operation (2,3) mentioned in the previous example is assigned to machining centre 1, that is, $X_{2,3,1} = 1$ and operation (4,1) is assigned to machining centre 2, that is $X_{4,1,2} = 1$. Since both the operations are of the same type the function $\phi(i,j)$ will give the same value

for both as

$$\phi(2,3) = \phi(4,1) = 1$$

Since the operation (2,3) is assigned to machining centre 1, to make the assignment practically feasible, the corresponding 'Milling" tool has to be loaded in the machining centre or equivalently $Z_{1,1}$ should be 1. But conversely it is not true in this example that the operation (4,1) which is also of type milling has to be assigned to the same machining centre, hence when $Z_{1,1} = 1$, $X_{4,1,1}$ need not be one.

The above said property can be used to reduce the quadratic term to a linear one, as,

$$Z_{\phi(i,j),k} - X_{i,j,k} \geq 0 \qquad i = 1,2..P;\ j = 1,2..O_i;\ k = 1,2..M$$

Thus the non-linear tool slot constraint is replaced by two sets of linear constraints such as

$$\sum_{u=1}^{NW} Z_{u,k}\, t_u \leq b_k \qquad k = 1,2,...M \qquad (2a)$$

$$Z_{\phi(i,j),k} - X_{i,j,k} \geq 0 \quad i = 1,2..P;\ j = 1,2..O_i;\ k = 1,2..M \quad (2b)$$

Tool assignment constraint

Since the new variable set $Z_{u,k}$ is specific to the type of tools, the non-linear constraint given by eqn.(4) can be

simplified as

$$\sum_{k=1}^{M} Z_{u,k} \leq C_u \tag{4a}$$

Summarizing the linear form of the original formulation,

$$\text{Max} \sum_{i=1}^{P} \sum_{j=1}^{O_i-1} \sum_{k=1}^{M} Y_{i,j,k} \tag{1a}$$

subject to

(1b), (1c), (2a), (2b), (3), (4a) and (5).

Discussion of the Formulation

This formulation is simpler in the sense that the number of variables and number of constraints are less than those in the formulation based on linearizing the original formulation by replacing every non-linear term by a variable and two constraints. This is especially so when the parts have more common type of operations.

Number of variables

$$= TO \times M + U \times M + (TO - P) \times M$$

Number of constraints

$$= TO \times M + TO + M + 2 \times (TO - P) \times M$$

where

M = Number of machining centres

P = Number of parts

TO = Total number of operations

$$= \sum_{i=1}^{P} O_i$$

U = Number of type of operations

$$= |W|$$

Some times, in this type of formulation, since the assignment of the operation type (variable $Z_{u,k}$) is not bounded from above, it may be possible that there will be redundant assignment of some operation type u in the machine whose tool magazine capacity is relatively larger. But our loading decision is based on the variable set $X_{i,j,k}$ only, hence this will not create any problem.

Solution Methodology

The above 0-1 linear integer programming formulation can be solved by branch and bound technique, which involves solving the continuous LP form of the problem initially and branching on the variable which takes non integer value, by assigning 0 and 1 on each branch. At every node the bound is calculated by solving the corresponding LP. This procedure requires more calculations as an LP has to be solved at each node, but may give tighter bounds. An implicit enumeration technique suggested by Balas [1] (Balas additive algorithm) can also be used, to solve the problem with lesser calculation as it does not require LP to be solved for finding bounds. But this procedure may need larger enumeration. However, the exponential increase in time requirement by both these solution methodologies, with respect to data length makes the problem computationally intractable for real life situations as the data involved would be larger.

Many moderate size problems were solved using the optimization package LINDO which uses the branch and bound technique. The CPU time was observed to be significantly high. For 10 problems with an average of 100 variables, the average CPU time to solve them was 11.74 minutes.

Relaxing the Assumption (iii)

The assumption (iii), that is all the machining centres are assumed to be capable of performing all the operations, can be easily relaxed without much of change in the formulation. When an operation (i,j) is specific to a certain machining centre k or it cannot be performed by that machining centre, the corresponding assignment variable $X_{i,j,k}$ should be preassigned a value 1 or 0 respectively.

3.1.3 Minimizing the Part Movement and Balancing the Load

When assigning the operations to the machining centres with the objective of minimizing the part movement, it may so happen that a machining centre with larger tool magazine capacity or machine which can perform more number of operation types, will get assigned more number of operations resulting to heavy unbalance in the workload among the machining centre. This unbalance will increase the machining centre idle time which is most important cost related measure of system performance in the context of FMS involving expensive machine tools and equipments. This can be remedied by considering the combined objective of part movement minimization and load balancing, in the loading problem.

The conceptual model of FMS described in Sec. 3.1.1 and the assumptions and notations mentioned in Sec. 3.1.2 are used in this formulation.

Objective Function

The balance in workload among the machining centres can be achieved by minimizing the workload in the bottleneck machining centre, which should be done at the minimum cost of separating the successive operations.

The objective function can be expressed as

$$\text{Max} \sum_{i=1}^{P} \sum_{j=1}^{O_i - 1} \sum_{k=1}^{M} W_i \, Y_{i,j,k} - \delta$$

where

$Y_{i,j,k}$ has the same meaning as in Sec. 3.1.2, that is,

$Y_{i,j,k} = X_{i,j,k} \times X_{i,j+1,k}$

δ = upper bound on the machining centres workload

≥ 0

Constraints

Machine Loading Constraint:

All the machines should have load less than or equal to the upper bound (δ) value, this can be described as

$$\sum_{i=1}^{P} \sum_{j=1}^{O_i} X_{i,j,k} \, P_{i,j,k} \leq \delta \qquad k = 1,2...M \tag{6}$$

All other constraints given by eqns.(1b), (1c), (2a), (2b), (3), (4a) and (5) which are described in Sec. 3.1.2 have to be considered.

The weight W_i represents the importance of the objective of minimizing part movement. A reasonable value of W_i would be the transportation time for the part i between the machining centres so that when there is a decrement in δ at the cost of separating successive operation of the part i, the formulation will be sensitive that the part will require additional transportation time W_i. In the FMS setup where machining centres are at equal distance from each other and there is not much variability amongst

the part types, the transportation time may be taken to be the same, that is, $W_i = W \;\forall\; i$.

This 0-1 mixed linear integer programming problem can be solved by using branch and bound technique described in the previous section.

3.2 Numerical Illustration

Let us consider the following problem

Number of part type P = 4

Operation type and sequence (i,j) = (Part index, Operation index)

Part type (i)	Number of O_i	Operation Code and Sequence (j) 1	2	3	4
1	4	G	H	D	F
2	3	H	A	E	
3	4	B	D	H	D
4	3	B	G	B	

Operation type details

Operation Type index (u)	1	2	3	4	5	6	7
Operation Code	A	B	D	E	F	G	H
No. of slots required (t_u)	4	1	9	2	5	8	7
No. of tool copies available (C_u)	3	2	2	3	2	1	3

Number of machining centres $M = 3$

Tool magazine capacity (Number of slots) (b_k)

M/C 1	M/C 2	M/C 3
15	15	15

We consider the problem of minimizing the part movement only.

The set W of operation types is defined as

$$W = \{A, B, D, E, F, G, H\}$$

The conceptual function ϕ can be defined as

$\phi(1,2)$ = The index of the operation type of operation (1,2) in the set W

= 7

Similarly for all i and j.

The formulation can be written as

Max (eqn. 1a)

$$Y_{1,1,1} + Y_{1,1,2} + Y_{1,1,3} + Y_{1,2,1} + \dots + Y_{4,2,3}$$

St

1) Tool slot constraint (eqn. 2a)

$$4Z_{1,1} + Z_{2,1} + 9Z_{3,1} + 2Z_{4,1} + 5Z_{5,1} + 8Z_{6,1} + 7Z_{7,1} \leq 15$$
$$4Z_{1,2} + Z_{2,2} + 9Z_{3,2} + 2Z_{4,2} + 5Z_{5,2} + 8Z_{6,2} + 7Z_{7,2} \leq 15$$
$$4Z_{1,3} + Z_{2,3} + 9Z_{3,3} + 2Z_{4,3} + 5Z_{5,3} + 8Z_{6,3} + 7Z_{7,3} \leq 15$$

After applying the function $\phi(i,j)$ for all i and j, we have the constraint set given by eqn.(2b) as

$$
\begin{array}{lll}
Z_{6,1} - X_{1,1,1} \geq 0 & Z_{6,2} - X_{1,1,2} \geq 0 & Z_{6,3} - X_{1,1,3} \geq 0 \\
Z_{7,1} - X_{1,2,1} \geq 0 & Z_{7,2} - X_{1,2,2} \geq 0 & Z_{7,3} - X_{1,2,3} \geq 0 \\
Z_{3,1} - X_{1,3,1} \geq 0 & Z_{3,2} - X_{1,3,2} \geq 0 & Z_{3,3} - X_{1,3,3} \geq 0 \\
.. \quad .. \quad .. & .. \quad .. \quad .. & .. \quad .. \quad .. \\
.. \quad .. \quad .. & .. \quad .. \quad .. & .. \quad .. \quad .. \\
Z_{2,1} - X_{4,3,1} \geq 0 & Z_{2,2} - X_{4,3,2} \geq 0 & Z_{2,3} - X_{4,3,3} \geq 0
\end{array}
$$

2) Unique job routing constraints (eqn. 3)

$$
\begin{array}{l}
X_{1,1,1} + X_{1,1,2} + X_{1,1,3} = 1 \\
X_{1,2,1} + X_{1,2,2} + X_{1,2,3} = 1 \\
.. \quad .. \quad .. \\
.. \quad .. \quad .. \\
X_{4,3,1} + X_{4,3,2} + X_{4,3,3} = 1
\end{array}
$$

3) Tool assignment constraint (eqn. 4a)

This constraint will be active for a tool type u when

$C_u < \mathrm{Min}\ \{|T_u|, M\}$

u	Operation Type Code	C_u	T_u	Min $\{|T_u|, M\}$
1	A	3	(2,2)	1
2	B	2	(3,1),(4,1),(4,3)	3
3	B	2	(1,3),(3,2)	2
4	E	3	(2,3)	1
5	F	2	(1,4)	1
6	G	1	(1,1),(4,2)	2
7	H	3	(2,1),(3,3)	2

From the table the constraint for the tool type 2 and 6 will be active. After eliminating redundant constraints the constraint set becomes

$$Z_{2,1} + Z_{2,2} + Z_{2,3} \leq 2$$
$$Z_{6,1} + Z_{6,2} + Z_{6,3} \leq 1$$

4) Linearizing constraint set (eqn. 1a)

$$X_{1,1,1}+X_{1,2,1}-Y_{1,1,1} \leq 1 \qquad X_{1,1,2}+X_{1,2,2}-Y_{1,1,2} \leq 1$$
$$X_{1,2,1}+X_{1,3,1}-Y_{1,2,1} \leq 1 \qquad X_{1,2,2}+X_{1,3,2}-Y_{1,2,2} \leq 1$$
$$\cdots \quad \cdots \qquad \cdots \quad \cdots$$
$$\cdots \quad \cdots \qquad \cdots \quad \cdots$$
$$X_{4,2,1}+X_{4,3,1}-Y_{4,2,1} \leq 1 \qquad X_{4,2,2}+X_{4,3,2}-Y_{4,2,2} \leq 1$$

$$X_{1,1,3}+X_{1,2,3}-Y_{1,1,3} \leq 1$$
$$X_{1,2,3}+X_{1,3,3}-Y_{1,2,3} \leq 1$$
$$\cdots \quad \cdots$$
$$\cdots \quad \cdots$$
$$X_{4,2,3}+X_{4,3,3}-Y_{4,2,3} \leq 1$$

4) Linearizing constraint set (eqn. 1b)

$$-X_{1,1,1}-X_{1,2,1}+2Y_{1,1,1} \leq 0 \qquad -X_{1,1,2}-X_{1,2,2}+2Y_{1,1,2} \leq 0$$
$$-X_{1,2,1}-X_{1,3,1}+2Y_{1,2,1} \leq 0 \qquad -X_{1,2,2}-X_{1,3,2}+2Y_{1,2,2} \leq 0$$
$$\cdots \quad \cdots \quad \cdots \qquad \cdots \quad \cdots \quad \cdots$$
$$\cdots \quad \cdots \quad \cdots \qquad \cdots \quad \cdots \quad \cdots$$
$$-X_{4,2,1}-X_{4,3,1}+2Y_{4,2,1} \leq 0 \qquad -X_{4,2,2}-X_{4,3,2}+2Y_{4,2,2} \leq 0$$

$$-X_{1,1,3}-X_{1,2,3}+2Y_{1,1,3} \leq 0$$

$$-X_{1,2,3}-X_{1,3,3}+2Y_{1,2,3} \leq 0$$

.. .. ..

.. .. ..

$$-X_{4,2,3}-X_{4,3,3}+2Y_{4,2,3} \leq 0$$

6) Integrality constraints

$X_{i,j,k}$ = 0 or 1 $\quad i = 1,2,3,4; \quad j = 1,2..O_i; \quad K = 1,2,3$

$Z_{u,k}$ = 0 or 1 $\quad u = 1,2..7; \quad k = 1,2,3$

$Y_{i,j,k}$ = 0 or 1 $\quad i = 1,2,3,4; \quad j = 1,2..O_i; \quad K = 1,2,3$

The problem is solved using LINDO, the optimal solution is as follows

Machining Centre	Partwise operation index (Part, operation)	Operation type code
1	(1,1),(1,2),(3,3),(4,2)	D,F,B
2	(2,1),(2,2),(2,3),(4,1),(4,3)	A,B,H,E
3	(1,3),(1,4),(3,1),(3,2),(3,4)	G,H

Objective function value = No. of successive operations assigned together

= 5

CHAPTER IV

RANDOM FMS

In this chapter, we consider the loading problem in random FMS. In random FMS, a large family of parts having a wide range of characteristics are produced and the product mix is not completely defined at the time of installing the system. Hence general purpose machine tools will be employed.

4.1 Mathematical Programming Formulation for Loading

In random FMS, the orders for various part types arrive in random manner. It is assumed that an order is for only one part type. A part type may require several operations. To facilitate the planning procedure, planning horizon can be divided into various scheduling periods. The length of the scheduling period will correspond to the period accountability imposed by management upon the shop. The operation allocation is done at the start of every scheduling period by considering the parts that have been removed in the previous scheduling period and the fresh parts that are expected to be processed in the current scheduling period.

The loading problem can be specified as selecting a subset of jobs from the job pool and assigning them to the appropriate machining centres with certain objective. Here we consider the

objective of minimizing the part movements between the machining centres. Notations used in section 3.1.2 are assumed for this formulation.

Objective Function

The objective is same as that of the loading problem in dedicated FMS, the expression given by equation (1a) described in section 3.1.2 is used here without any change.

Constraints

Unique job routings

Out of P part types some may not be selected for loading in the current scheduling period, hence constraint set given by equation (3) is modified as

$$\sum_{k=1}^{M} X_{i,j,k} \leq 1 \quad i = 1,2..P;\ j = 1,2..O_i \tag{3a}$$

Non splitting of the job

As a job cannot be split its operations assignment should be equal to the total operations required, that is,

$$\sum_{j=1}^{O_i} \sum_{k=1}^{M} X_{i,j,k} = X_i \times O_i \quad i = 1,2..P$$

The new variable X_i is defined as

$$X_i = \begin{cases} 1 & \text{when part i is selected for loading in the current scheduling period} \\ 0 & \text{otherwise} \end{cases}$$

Machining centre capacity constraint

The load assigned to a machining centre can be restricted to the length of the scheduling period as

$$\sum_{i=1}^{P} p_{i,j,k} \; X_{i,j,k} \leq H$$

where

H = length of a scheduling period

Other constraint sets such as given by equations (1b), (1c), (2a), (2b), (4a) and (5) described in section 3.1.2. are applicable here.

Solution Methedology

Since the planning horizon is divided into scheduling periods, the number of parts to be considered for the loading decision in a scheduling period is comprised of parts that are not selected in the previous scheduling period and the parts that arrive in the current scheduling period. After knowing the job pool, the loading problem can be solved by branch and bound technique.

4.2 Loading and Sequencing: A Simulation Approach

Since the manufacturing system performance depends on the complete scheduling which is comprised of loading and sequencing,

it is appropriate and necessary to study these related activities in conjunction with each other. It is estimated that a mathematical model for complete scheduling problem, that is, loading and sequencing jointly, will be very complex.Therefore simulation is considered to be an appropriate tool for this composite problem.

4.2.1 General Description

Simulation is a procedure (numerical or otherwise) for conducting experiments through the use of mathematical and/or logical models as a means of depicting behaviour of an operating system (or components thereof) over extended periods of time (real or created) [4]. Any simulation process contains basically the following four major phases such as, (1) Problem definition (2) Model construction (3) Model verification and validation (4) experimentation. In the context of the problem under study, the phases are described in detail further.

(1) Problem definition

As any model representing the real system many times involves unavoidable approximations which make it to behave in a substantially different manner from the real behaviour, it may not be so appropriate to have objectives of predicting the system performance. However, for the FMS simulation, the objective of comparing the loading policies in conjunction with the dispatching rules with respect to the system performance measures such as machining centre utilization, transportation vehicle

utilization, mean flow time and tardiness of the jobs, could be more meaningful.

Following loading policies can be considered for the study

1. (LP 1) Loading the machining centres with the objective of part movement minimization, that is, loading using the analytical solution obtained by solving the problem as per the formulation described in the previous section.

2. (LP 2) Loading in the sequence of arrival of jobs with load balancing as the objective, that is, job which comes early and the machining centre which has minimum load are given high priority.

Other loading policies such as (1) loading for work load balancing using analytical solution obtained as per the formulation suggested by Shanker [16] and (2) loading for work load balancing and minimization of the number of late jobs using solution from heuristic proposed in the same paper [16], and loading policies with objectives suggested by stocke[7] can also be considered for complete comparison study.

The above described loading policies can be examined in combination with the following commonly described dispatching rules.

1) FIFO - First In First Out

2) SPT - Shortest Processing Time first

3) LPT - Longest Processing Time first

4) MOPR - Most Operations Remaining First

Some of the other despatching rules listed by Gupta V.P et al [8] can also be taken into consideration.

The objective is essentially to create report as given in the tables 1 and 3, through which conclusions about the loading policies and dispatching rules can be drawn by observing their effect in the system performance.

(2) Model Construction

For the purpose of simulation the model is a representation in which the elements of the problem (or system) are defined in terms of arithmetic (or) logical processes [4]

(a) Variables and parameters of the system

Size of FMS: The size of FMS is determined by the number of machine tools and transportation vehicles it contains. When the simulation study is made for an existing FMS, the size is predefined. If it is not so, approximate idea can be obtained by observing the distribution of the number of existing FMS against the number of machining centres in the system which is tabulated in reference [16].

O'Graday and Menon [14] observe that the number of machines per FMS configuration in the existing installations reviewed are with in the range of 2-11 workstations per FMS with a sufficient proportion in the lower half of that band.

Job arrival: In random FMS the jobs arrive in random manner. The interarrival time can be approximated to a known distribution such as exponential or Erlang distribution otherwise empirical distribution can be described using the past data.

Number operations and processing time: The number of operations per part and the operations type and their processing time should be given the approximate distribution they follow.

Number of type of operations: The number of types of operations which will be required by the jobs which will arrive during the whole simulation period should be specified.

Batch size: One of the major economic forces observed to be driving the rapid implementation of FMS is the well recognized need to reduce work-in-process inventory and increase machine utilization in small batch manufacturing. The batch size for each arriving order may be assumed to be following certain distribution. The decision with respect to completing a batch, that is, whether a batch can be split among the scheduling periods or it should be completed with in a scheduling period, should be made.

Tool magazine capacity: The number of slots in the tool magazine of the machining centres should be given, it may vary from 6 to 100 depending upon the type of magazine and machine tools in the FMS.

Scheduling period: Normal shift period of a working day can be taken as a scheduling period.

Transportation time: The part movement time accross the machining centres can be determined as per the configuration of the FMS.

b) States, events and clocks

One key to building good model is the adequate definition of states. Built into the definition must be enough information about the history, so that, given the current state, the past is statistically irrelevant for predicting all future behaviour pertinent to the application at hand [3]. The state of a system is represented by the status of various elements of the system. Number of jobs at each working centre with their characteristics (e.g., remaining work content) and the jobs waiting for transportation vehicles to be moved from or to the machining crentres could be the state components of the FMS under consideration.

The times at which the system enters a state are called event epochs. The corresponding state changes are called events. The possible events in a random FMS are

1) arrival of a job

2) beginning and end of machining process

3) beginning and end of part movement

Time control is generally divided into two classes. The two typical types are uniform time flow and variable time flow. With uniform time flow, the model is advanced and processed through each and every time period simulated at fixed steps or intervals. Variable or noxt-event time flow mechanism causes time to be

incremented between only those periods that have events occurring. The model is processed only at these times and performance figures adjusted to account for the periods skipped. In random FMS the events may not be regular to apply uniform time flow. Hence a variable time flow can be followed and the simulation clock will be driven by a dynamic event list so that time skips from one event epoch to the next. Nothing happens between epochs. There are two main ways to view the clock.

i) event orientation: For each possible event there is a subroutine that determines what other events get triggered and their respective provisional activation times. The clock mechanism then puts these activation times on the event list with pointers to the corresponding events and then it activates the next event due.

ii) Process orientation: All the code that concerns one process (e.g., job) is grouped together in one subroutine. An event list is kept for each process, and a master list contains the next event due in each list. The head of the master list points to the next event due. The clock mechanism activates it.

Either one of the orientation can be considered depending on the flexibility of the language used. A process oriented simulation usually requires a special purpose language including a co-routine mechanism.

c) Stochastic variate generation Stochastic variates are generated normally by manipulating pseudo random numbers calculated by the computer, most computer facilities include such

a generator in their software libraries. When using special purpose simulation languages, functions for standard distributions will be provided. The variates for the system variable such as number of operations per part, batch size, processing time of an operation which can be assumed to have uniform distribution can be generated by simple manipulation of random numbers. The type for each operation can be specified by generating uniform integer numbers between 1 and the number of type of operation for each operation. The integer generated can be taken as the operation type (code) for the corresponding operation. By doing so equal chance is given for each type of operation. Some times some operation type may be required relatively for more number of part types. In such cases, suitably designed conversion tables can be used to transform the random number to the type of operation.

d) Variance reduction Variance reduction technique basically try to reduce the true variance of the sample mean. Some of the standard techniques are common random number stream, antithetic variates, control variates, stratification and importance sampling. Since the basic objective of the simulation study is to make comparative statements over the loading policies and dispatch rules, the variance of the difference in their performance has to be reduced. This can be done by making the simulation runs as similar as possible, by doing so, the differences in performance can be attributed to policies and not to the chance occurrence of a devastating event during the simulation of one policy but not of other.

e) Simulation language This discrete event simulation programming can be done using any of the general purpose languages like Pascal, Basic or Fortran by using event oriented view of clock mechanism. Special discrete event simulation languages like SIMSCRIPT, GPSS can be used to programme with less effort. When SIMSCRIPT is used for this random FMS simulation, the activation process should be done externally because all the random variate except the transportation time would have been generated before the simulation is actually started.

3) Model verification and validation

Verification of a model is a process of checking that the simulation programme operates in the way that the model implementer thinks it does. This is an important activity, in that without satisfactory and explicit verification, it is possible for a model that appears to work satisfactorily but which gives answers that are actually erroneous. In the FMS simulation since the variates are already known, scheduling can be done manually for a set of data and this can be used to verify the programme.

Validation is one of the most critical activities performed in any simulation study. It is also one of the most difficult to accomplish satisfactorily. A validated model is one that has been proven to be a reasonable abstraction of the real world system it is intended to represent. Due to the approximations made in the model, the real system and the model will not have identical output distributions, thus , statistical tests of model

validity has limited use. The real question is the practical significance of any disparities. The usual approach to validation is to run the model with historical data and compare the model results with actual system results for the same historical period. This can be done when the simulation is run for the existing FMS. In the case of uninstalled FMS, data from similiar systems can be used to validate the model.

4) Experimentation

Generally there are two classes of experimentation deal with exploration of system behaviour and/or optimization of system parameters. The FMS simulation experimentation is mostly of first type. At the start of every scheduling period the machining centres have to be allocated operations as per the policy considered, for this the details of all the parts which are expected to arrive during the scheduling period should be known a priori. Hence it will be convenient to have all the arrivals generated for the entire simulation period in the beginning. The length of the scheduling period can be fixed by finite run criteria or steady state criteria. Normally, to attain steady state more number of runs have to be made. This will apparently increase the time involved as a time consuming loading problem has to be solved for each scheduling period when loading policy 1 (LP 1) is considered. Following are the major steps involved.

1) All the parameters such as number of machining centres, their tool magazine capacity, number of transportation vehicles are given.

2) Operations are allocated as per the loading policy

considered, for all scheduling period lies in the entire simulation length.

3) Simulation is run for all the scheduling periods.

4) Reports are generated.

The structure of the simulation procedure is given in figure 2. The above steps have to be repeated for all the required combinations of loading and sequencing rules. When steady state criteria is used to fix the simulation period, the step 3 and 4 has to be done scheduling period by period and after every scheduling period the end condition (confidence interval for the given performance measure) has to be checked. Sometimes when there is a need for optimization over the number of machining centre and/or transportation vehicels requied, the respective parameter's effect can be studied by changing its value suitably.

4.2.2 Illustration

For the purpose of illustrating the simulation approach, the following problem is considered. The values of parameters are decided in consideration with the time requirement to solve the loading problem. The values and distribution for the system variables are taken as in reference [16].

Parameters and Variables

Number of machine centres : 3

Number of auto guided vehicles (AGV) : 2

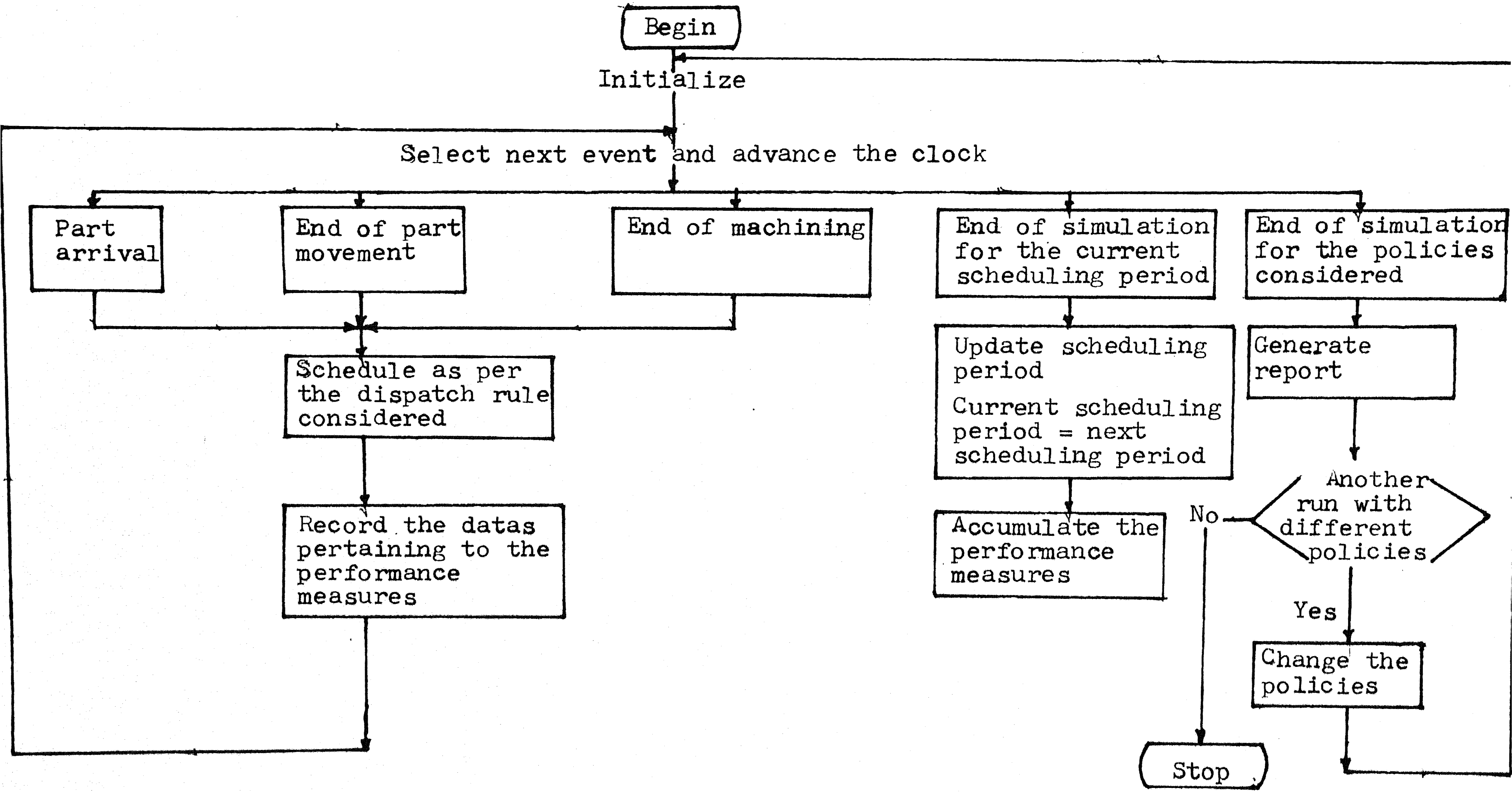


Fig. 2: The structure of FMS Simulation.

Tool Magazine capacity for each Machining Centre	: 15 slots
Jobs arrival	: Exponential distribution with mean 70 minutes
Number of operations	: Uniformly distributed between 3 and 5
Processing time of an operation	: Uniformly distributed between 6 and 30 minutes
Tool slot requirement per operation	: Uniformly distributed between 1 and 10 slots
Length of scheduling period	: 250 minutes

Policies Considered

Loading policy 1 (LP1) and 2 (LP2) and dispatching rules FIFO, SPT and LPT described in the previous section are considered.

Proformance Measures

Mean flow time for the jobs and utilization of machines are studied.

Assumptions and Decisions

1) The transportation time between machining centres is assumed to be constant. For experimentation, two different values, one equal to the mean processing time (18 min.) and the other equal

2) All the machines are assumed to be capable of performing all the operations.

3) The processing time for an operation is assumed to be independent of the machining centre.

4) When AGVs are not free the parts which arrive during the current scheduling periods, and those which had arrived during the previous scheduling period are placed in the loading area and waiting for AGVs to become free.

5) When a part is moved to the corresponding machining centre which is not free, it is placed in the temporary storage area of the machining centre. The storage area is assumed to be sufficient to accomodate all the parts expected to be in queue for the machining centre at a time.

6) Non delay schedule is assumed to be observed. In a non delay schedule, no machining centre or AGV is kept idle at a time when it could begin processing some operation. The dispatch rules are applied whenever there is competition for the resources.

The simulation programme is written in Turbo Pascal as per the detailed structure given in Figure 3. To start with all the random variates are generated. When considering loading policy 1, (LP1), the problem as formulated in section 5.1 is solved through the optimization package LINDO. As the time required for solving them is demandingly more, the simulation run is limited

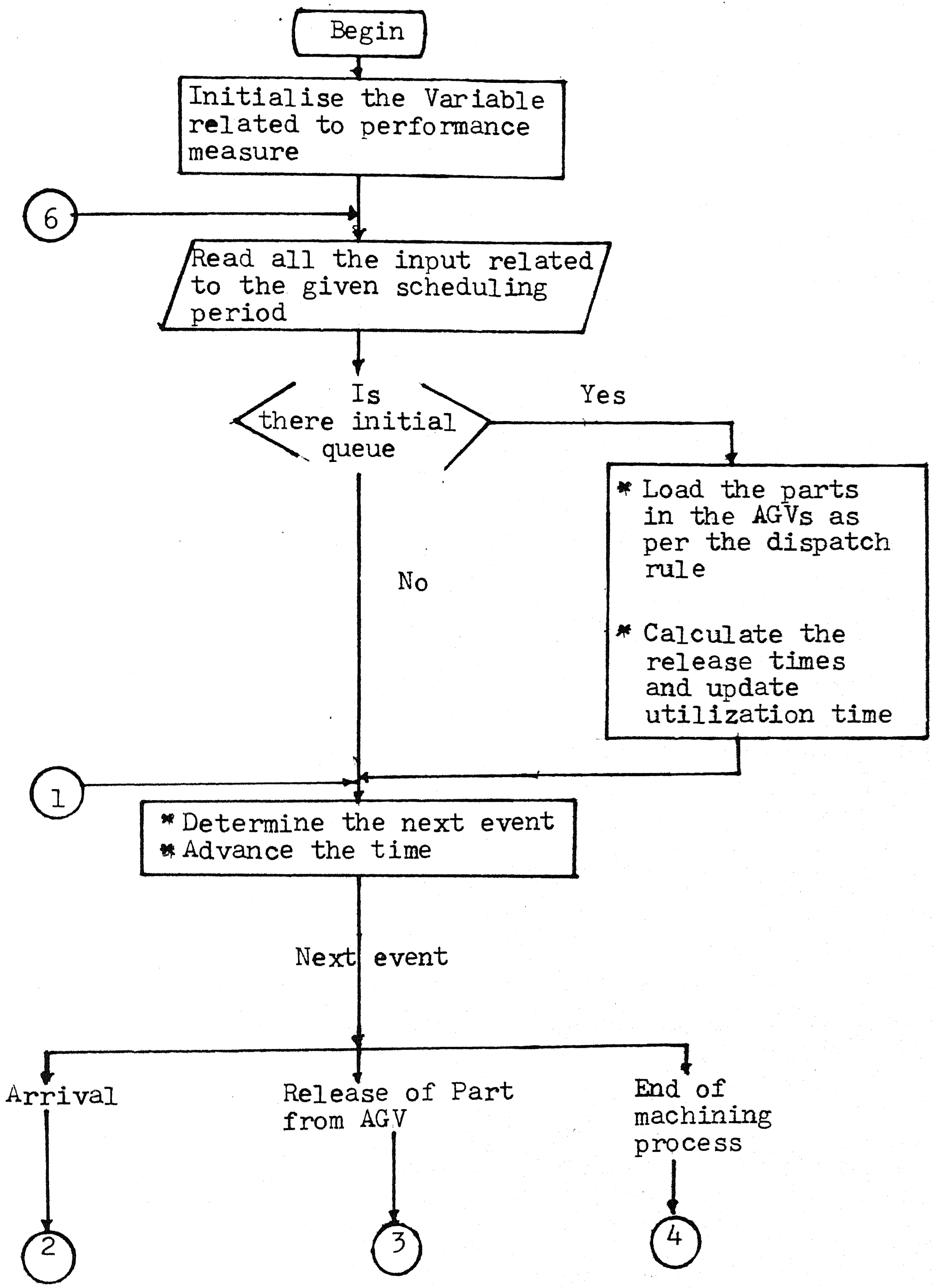
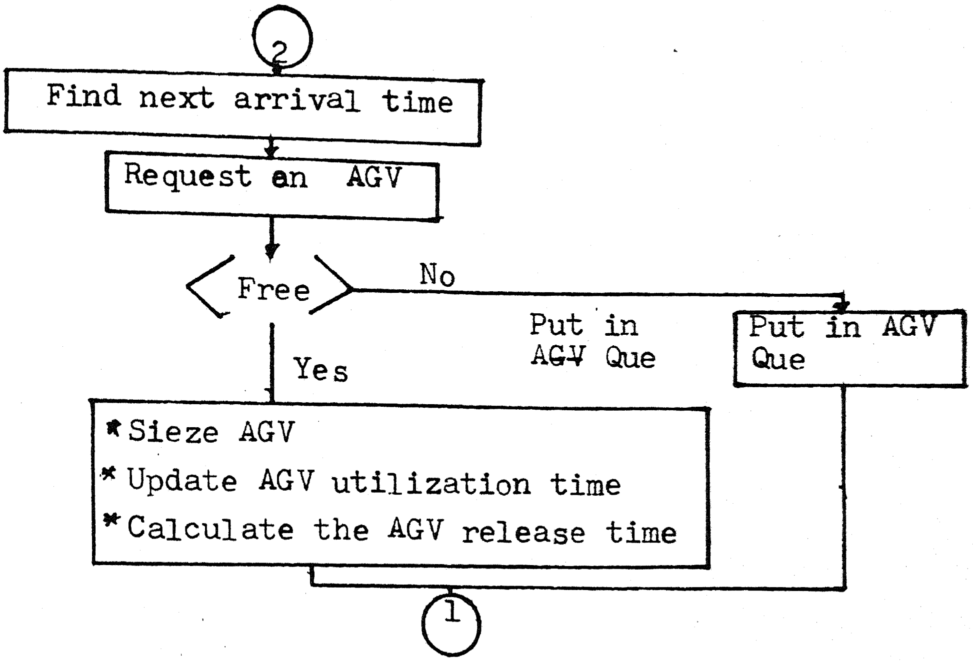
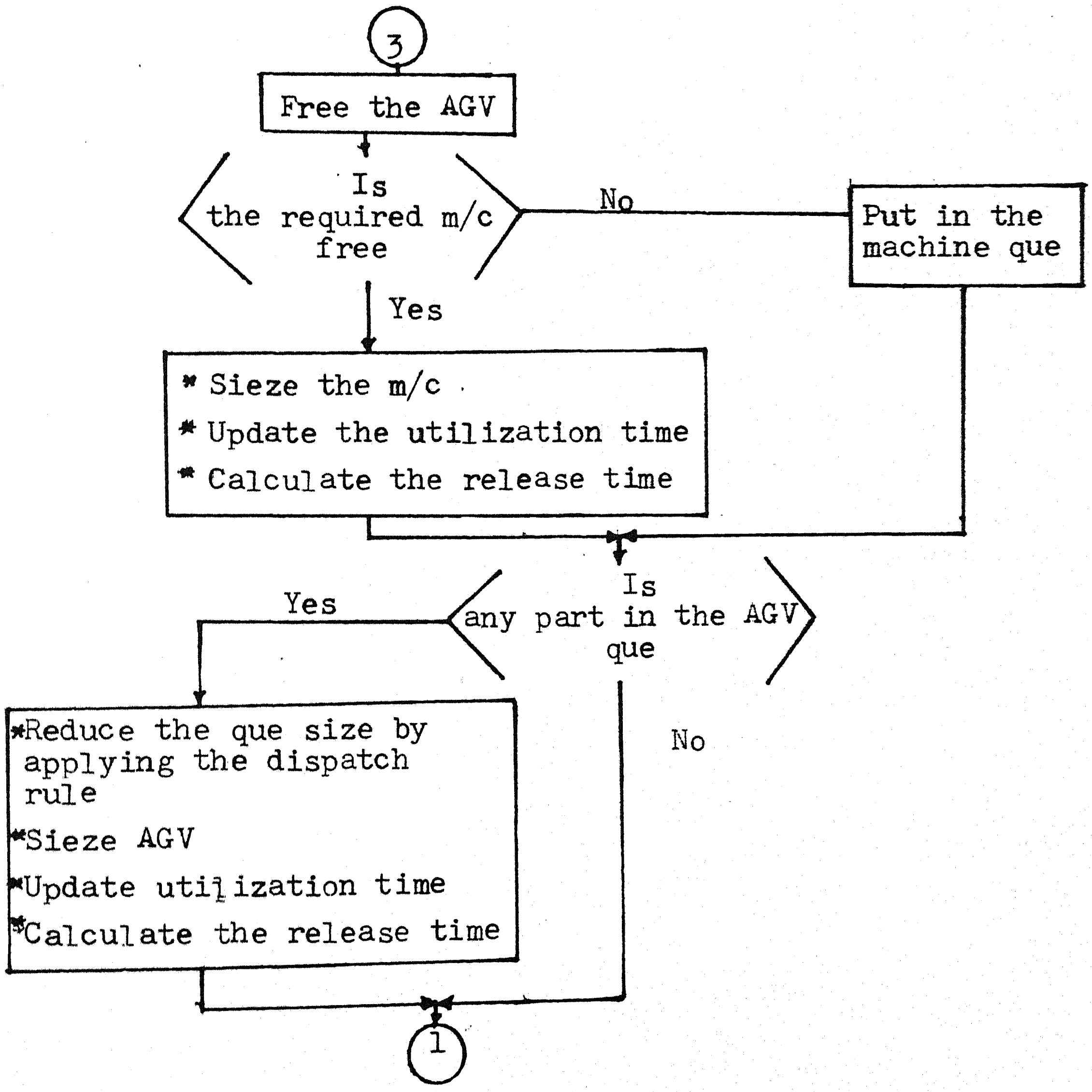


Fig. 3: The detailed simulation structure.

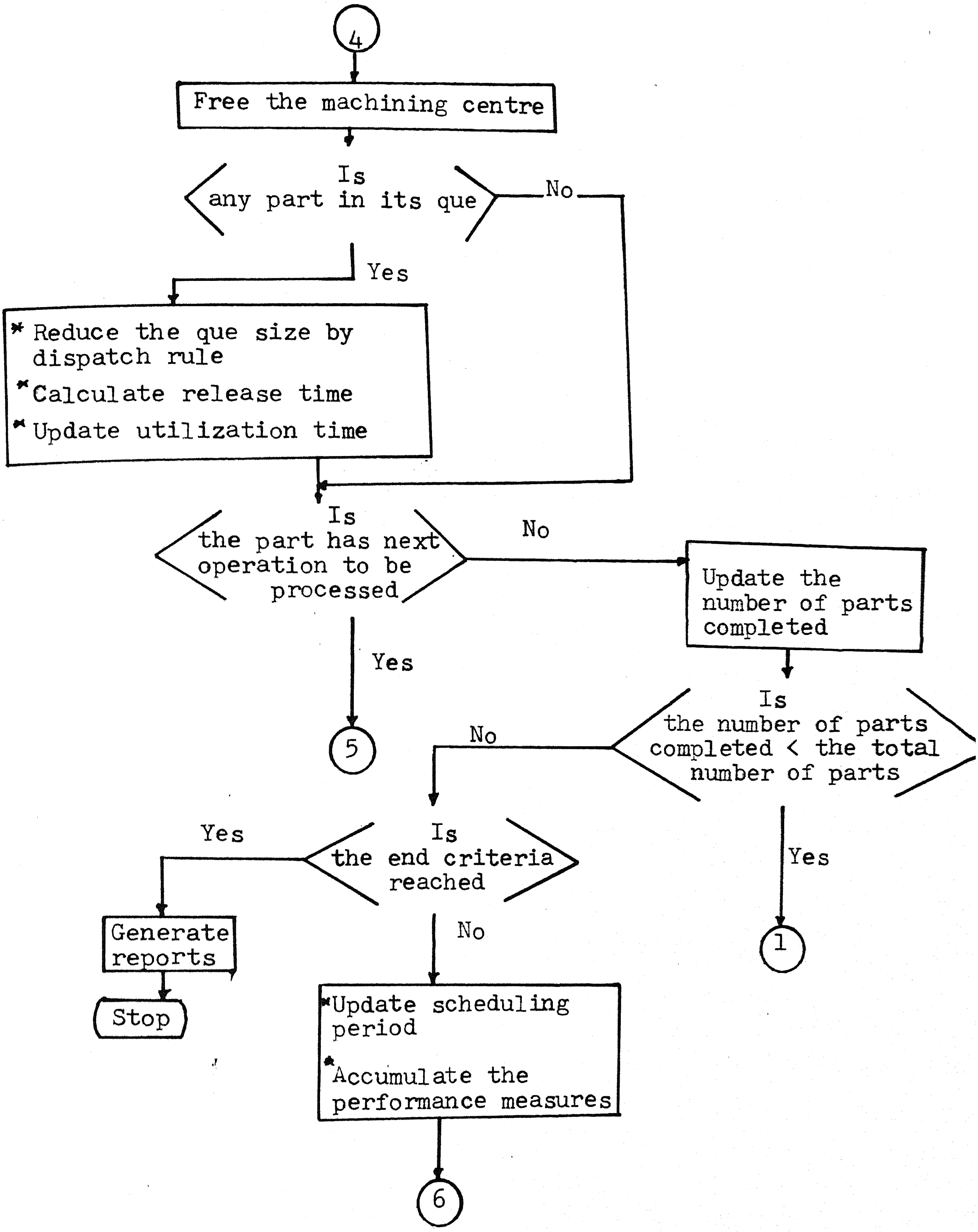
ARRIVAL MODULE



AGV RELEASE MODULE



M/C RELEASE MODULE



to 10 scheduling periods. The same random variables are used for all the combinations of loading policies and dispatching rules and transportation times. Observations are tabulated in Table 1,2 and 3.Results are graphically presented in Fig. 4. From the Table 3, it can be noticed that there is no significant difference in machine utilization among the policies. With respect to mean flow time from table 1, FIFO seems to give better values when compared to other dispatching rules. As it is expected the loading policy 1 gives the lesser mean flow time than the policy 2. Since the number of samples is very less, conclusions may not be valid, and require further study.

TABLE 1 : MEAN FLOWTIME (Min)

SCHED	Transportation time = Mean processing time (18 min)						Transportation time = Mean processing time (36 min)					
	POLICY 1 (LP1)			POLICY 2 (LP2)			POLICY 1 (LP1)			POLICY 2 (LP2)		
PERD	FIFO	SPT	LPT	FIFO	SPT	LPT	FIFO	SPT	LPT	FIFO	SPT	LPT
1	122.4	122.4	122.4	126.9	127	126.9	158.4	158.4	158.4	181.2	181.2	181
2	251.2	264.8	260.5	260.9	256	271.6	339.3	359.3	356.9	435.1	438.2	450
3	234.7	251.4	274.1	349.3	328	355.6	373.8	399.7	445.1	578.4	601.7	607
4	115.9	115.9	115.9	170	170	170	164.3	190.2	272.2	482.3	505.4	510
5	125.2	125.2	125.2	192.5	192	192.5	197.2	215.6	305.6	578.4	601.5	607
6	102.7	102.7	98.6	179	179	179	164.2	165.4	269.5	671.8	815.2	757
7	168.9	168.9	173.3	218.7	210	218.7	300.5	302.9	360	769.5	924	912
8	275.5	288.6	315.3	212.1	212	215.7	469.7	489.3	577	916	983.9	1069
9	124.4	123.7	127.6	157.5	161	170.7	381.8	390.1	481.1	970.3	1156	1082
10	180.1	186.1	173.3	250.2	257	271.1	433.1	414.9	531.4	1137	691	1239
AVG	170.1	175	178.6	211.7	209	217.2	298.3	308.6	375.8	672.2	690	748

TABLE 2 :UNBALANCE (Min)

SCHED PERD	POLICY 1 (LP1)	POLICY 2 (LP2)
1	28.4	18.69
2	60.65	26.45
3	45.55	45.57
4	92.46	34.41
5	75.77	19.56
6	57.75	53.16
7	51.32	33.21
8	77.35	51.27
9	32.35	75.21
10	119.86	50.01
AVG	64.15	40.75

TABLE 3 : MACHINE UTILIZATION (%)

SCHED	Transportation time = Mean processing time (18 min)						Transportation time = Mean processing time (36 min)					
	POLICY 1 (LP1)			POLICY 2 (LP2)			POLICY 1 (LP1)			POLICY 2 (LP2)		
PERD	FIFO	SPT	LPT	FIFO	SPT	LPT	FIFO	SPT	LPT	FIFO	SPT	LPT
1	29.37	29.37	29.37	29.65	29.7	29.65	25.24	25.24	25.24	25.51	25.51	25.5
2	52.26	47.81	40.63	43.78	47.1	42.92	39.27	35.71	30.57	32.57	30.84	30.5
3	55.68	62.7	65.79	31.66	31.6	31.6	52.42	52.42	43.59	22.46	22.46	22.5
4	11.94	11.94	11.94	15.96	15.9	15.96	18.03	18.03	18.03	10.74	10.74	10.7
5	39.59	39.59	39.59	42.22	42.2	42.22	33.97	38.52	33.97	28.77	28.77	27.5
6	29.01	29.01	29.01	38.94	38.9	38.94	28.73	28.73	36.74	29.0	27.04	24.7
7	42.5	42.5	39.03	40.23	40.3	40.23	31.36	31.36	27.74	25.42	28.41	25.4
8	47.5	50.08	43.17	38.02	38.0	37.52	38.23	39.27	34.25	27.14	25.66	28.7
9	34.7	33.68	41.84	43.17	40.9	37.45	31.23	32.31	33.01	28.23	27.3	29.9
10	34.89	34.89	32.9	41.59	41.6	45.31	31.99	42.6	31.99	31.86	39.6	38.0
AVG	37.34	38.15	37.32	36.42	36.6	36.18	33.3	34.42	31.51	26.97	26.63	25.9

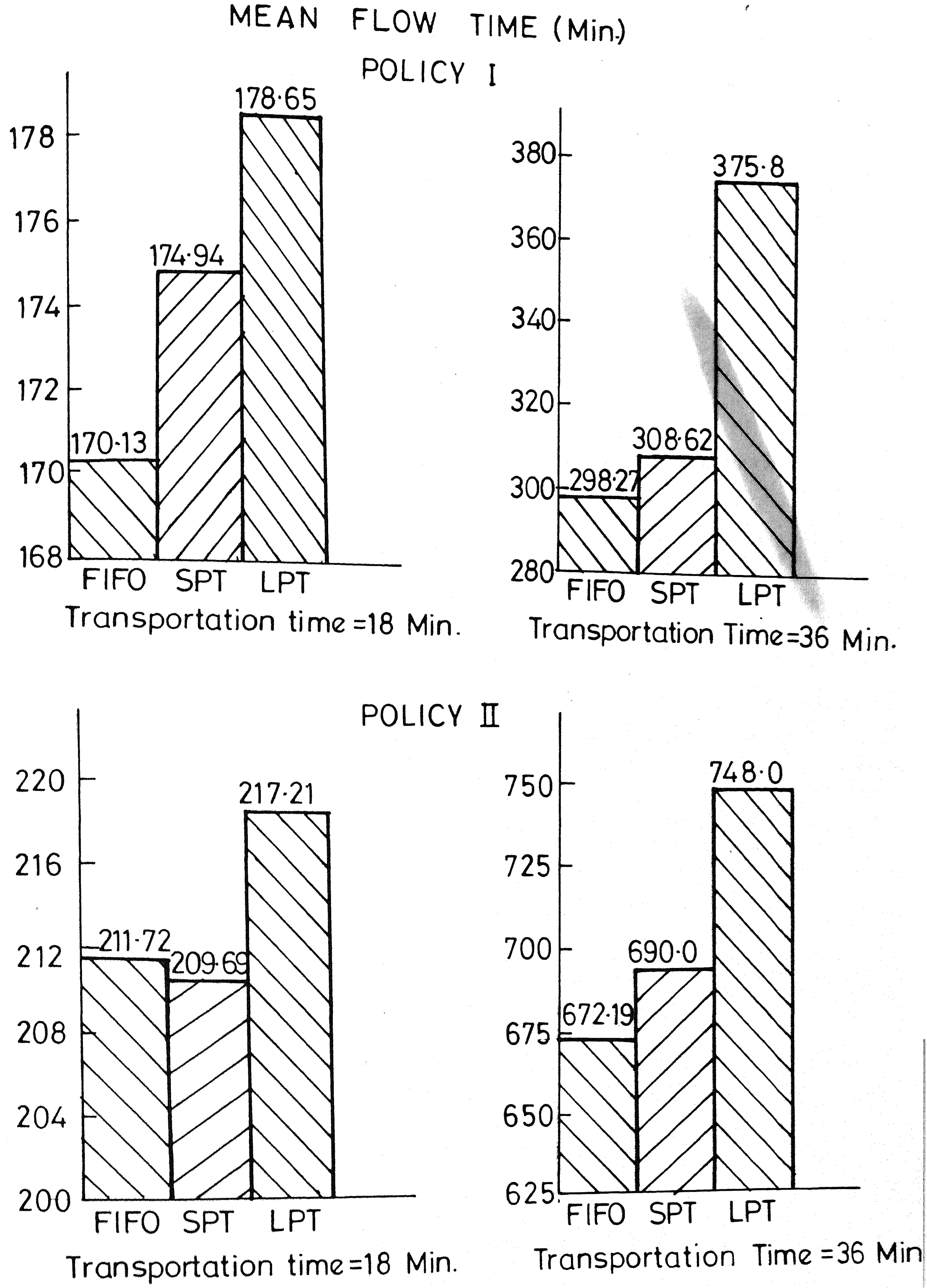


FIG. 4 SYSTEM PERFORMANCES FOR VARIOUS POLICIES

CHAPTER V

A SUPPORTING SYSTEM FOR LOADING AND SEQUENCING

The performance measures in connection with loading and sequencing of an FMS is influenced by many system dependent internal parameters and uncontrollable external variables and various changeable planning decisions. And many times a manufaturing system is expected to perform satisfactorily with respect to more than one objective. In view of this it is practically infeasible to find the optimum for the variables and decisions. In such situations providing a supporting system is the most viable alternative.

Objective of the System

Loading and sequencing together form the complete shop level scheduling problem in FMS. They can be solved independently with less effort, but the manufacturing system performance is the combined effect of both the decisions. The over all system performance is to a considerable extent dependent on the input charecteristics such as number of part types, the operations and their slot requirements etc. Hence it is meaningful to find satisfactory solution specific to the problem at hand by effeciently evaluating the various alternatives rather than trying to solve the highly complex general problem. So given the

problem the system facilitate in evaluating the various alternatives for loading and sequencing, in the light of their effect in the system performance criteria in concern.

System details

The system is designed for dedicated FMS environment. The following are the assumptions involved.

(1) All the machines are assumed to be capable of performing all the operations.

(2) The processing time of an operation is dependent only on the part type and not on the machining centre.

(3) The loading for the given data is assumed to be feasible.

(4) Since the optimization package (LINDO) used to solve the loading problem, has limitation on the number of integer variables, larger size problems are assumed to be solved through main frame LINDO and the solution file created should be present in the auxillary memory of the system used.

(5) The transportation time between the machining centres is assumed to be constant.

Initially operations are allocated to the machining centres with the objective of part movement minimization by solving the model described in section 3.1.2 using LINDO. It may result in heavy unbalance in workload among the machining centres. Hence balancing is done using a step by step heuristic procedure. Loading pattern obtained at each step is recorded for further consideration. The system consists of three modules such as

(1) problem solving module (2) load levelling module (3) Scheduling module. Each of them is described in detail further.

Problem solving module :- The data relevant to the loading problem such as part type with their operations sequence and processing time, operation types with their tool slot requirements, machining centres and their tool magazine capacities are received interactively. After receiving the data, the problem size interms of number of variables for loading problem with part movement minimization objective is calculated. If it exceeds the capacity of the optimization package then the problem is expected to have been solved through main frame version of the package and the solution file created should have been loaded in the system. If the problem size is with in the capacity, the loading problem is solved. Option is given to use old problem files.

Load levelling module :- In this module the loading done with the objective of part movement minimization is modified heuristically to get uniform workload among the machining centres by minimizing the the workload in the bottleneck machining centre at each step of the procedure, unidirectionally. This is explained in detail in the flow chart in fig.5. The loading obtained at every step of the heuristic procedure is recorded as candidate loading for further considerations.

Sheduling module :- All the considered loading including the one with part movement minimization as objective, are displayed and provision is made to see the workload in the machining centres graphically for each loading pattern. Any of the loading can be

PROBLEM SOLVING MODULE

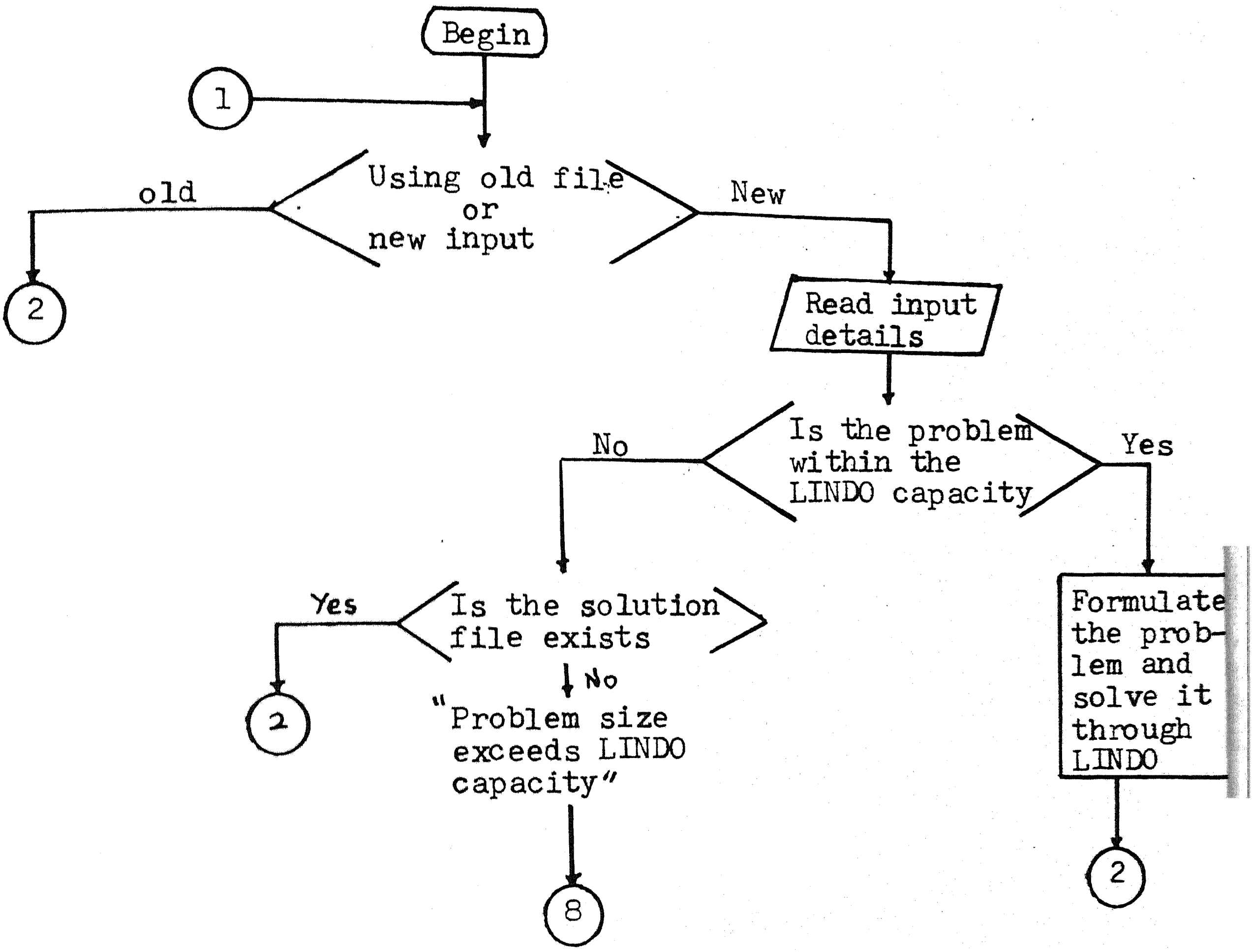
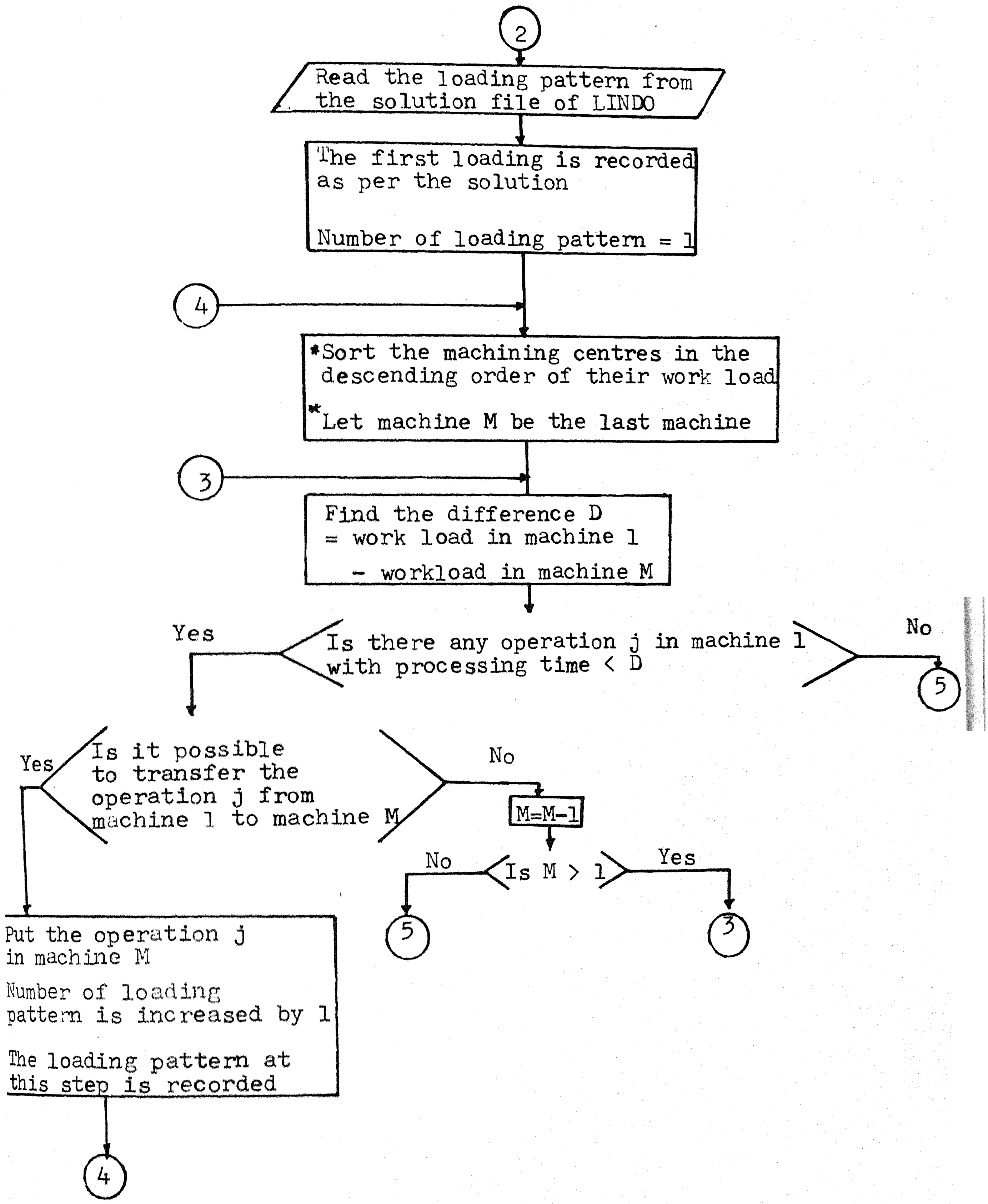
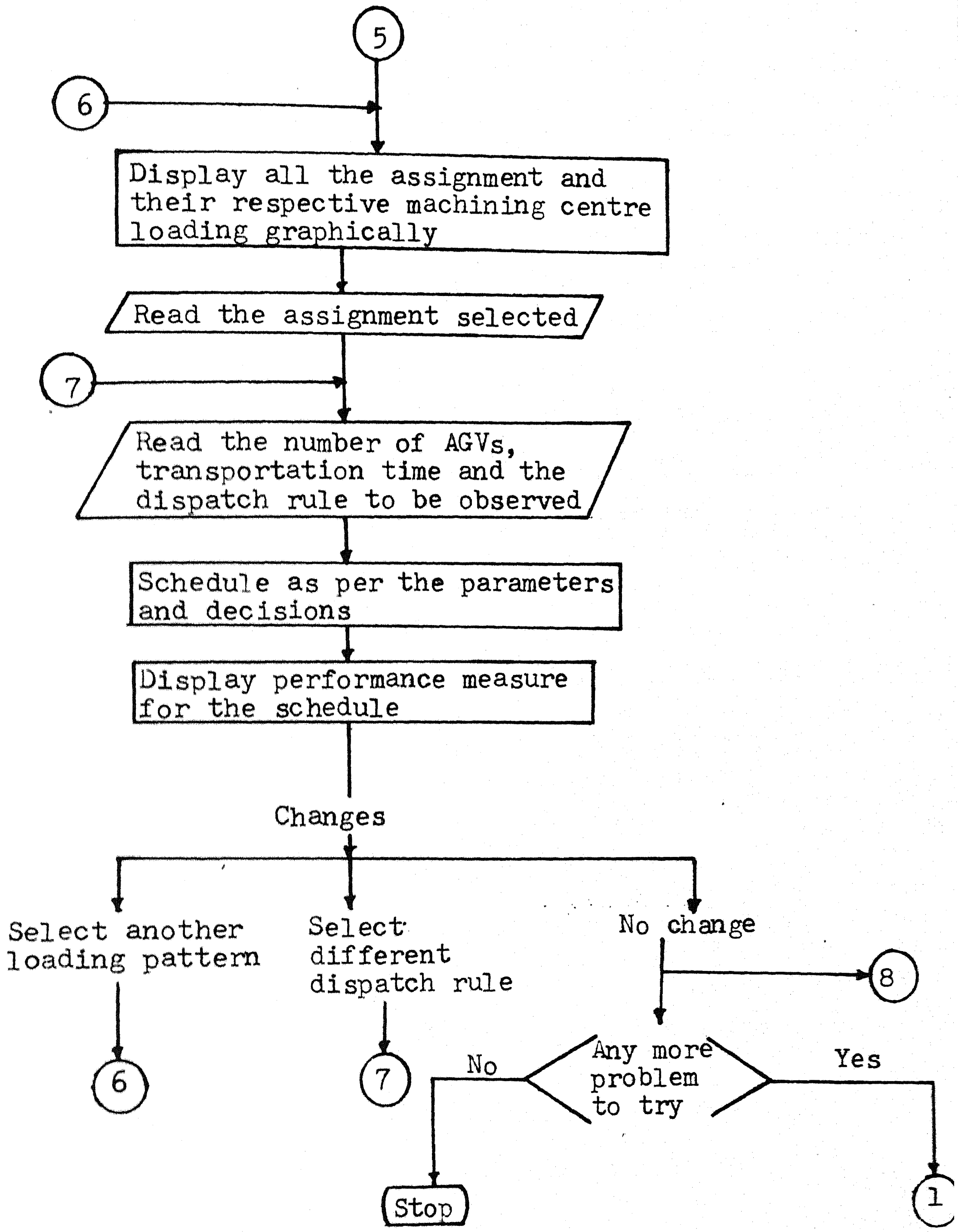


Fig. 5: Flow chart for the supporting system.

LOAD LEVELLING MODULE



SCHEDULING MODULE



selected for examining it in conjunction with the dispatch rules which will be observed. After selecting a loading pattern, dispatching rule to be cosidered can be selected optionally among the three comon sequencing rules such as FIFO, SPT, LPT, for carrying out the scheduling process. A non delay schedule is formed in consideration with the important subsystem of FMS, that is, the transportation system. The characteristics of the transportaion system such as the number of Auto Guided Vehicles (AGVs), their transportation time are to be given at this stage. The manufaturing system performance measures such as mean flowtime, machining centre and AGVs utilizations and parts completion times are displayed. Option is given to make changes in any or all of the following such as dispatch rles, number of AGVs, transportation time, loading pattern selected, if the system performance is not satisfactory. Change can be done till a satisfying solution is obtained.

The entire programme is written in TURBO PASCAL, for solving the loading problem LINDO is used. The interface between two is done through batch files.

Limitations

PARAMETER		MAXIMUM VALUE
Number of part types	:	10
Number of opertions per part type	:	5
Number of machining centres	:	5
Number of AGVs	:	5

The limitations are made to facilitate the process of output display.

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CHAPTER VI

CONCLUSIONS

The present thesis deals with the loading problem in both dedicated and random FMS. In dedicated FMS the problem is considered with important cost related objectives such as load balancing and part movement minimization. Although all the production planning problems are interdependent, assuming that part type selection, machine grouping, production ratio and resource allocation problem have been solved, the loading problem has been viewed as allocating the operations of the selected part types to the appropriate machining centres.

A simulation approach is developed for the combined problem of loading and sequencing in random FMS. Experimentation of the simulation model is carried out for two loading policies versus three dispatching rules. The following are the observations made based on a simulation run of ten scheduling periods. The loading with the objective of part movement minimization is observed to give better mean flow time than loading with workload balancing as the objective. In dispatching rules FIFO rule gives better values of mean flow time as compared to other rules such as SPT and LPT.

A supporting system for scheduling problem in dedicated FMS is designed and implemented to provide support in selecting the loading and sequenciing policies. The problem size is limited to

10 part types, each having 5 operations, 5 machining centres and 5 transportation vehicles.

Suggesitions for Future Research

1) As the time required to solve the exact loading problem is significantly high, simple and effective heuristics can be developed to get good solutions.

2) When effecient heuristic is used, the simulation model devloped can be studied with substantially more number of samples to make firm conclusions regarding the effect of loading policies and dispatch rules.

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